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Emergence and growth of cabbage seedlings in plastic, peat, paper, and newspaper containers

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Abstract: Cabbage (*Brassica oleracea*) seeds were germinated and grown for 35 days in an organic standard substrate contained in either plastic, peat, paper, or newspaper containers to determine whether the container material might affect growth. Days to emergence, days to first leaf, and developmental morphological traits and physiological characteristics were monitored. Differences in evaporation and pH of water in contact with the containers were measured in separate experiments. Evaporation was lowest from plastic and highest from peat containers, while pH was lowest with water in contact with peat containers. Plant growth was fastest and most robust in plastic containers as demonstrated by their shoot height, stem diameter, and root and shoot dry weights. Seedlings grown in newspaper containers presented exceedingly poor growth and showed signs of stress.

Subjects: Crop Science; Horticulture; Agriculture and Food; Agronomy

Keywords: *Brassica oleracea*; bedding plants; evaporation; leaf diameter; metals; recycled paper

1. Introduction

Cabbage plants (*Brassica oleracea*) are commonly started in containers before field transplanting in cold climate regions throughout the world including North America and Northern Europe. While commercial growers typically start seedlings in plastic flats, home gardeners may start seedlings in peat, paper, or plastic cups, homemade newspaper cups, or other makeshift containers. Plastic containers are preferred by some growers because they are lightweight and inexpensive. However, the non-biodegradability of plastics means that the seedlings grown in plastic containers must be removed before planting, which may contribute to transplant shock. The containers must be either

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PUBLIC INTEREST STATEMENT

Cabbage plants are commonly started in containers before field transplanting in northern regions. While commercial growers typically start seedlings in plastic flats, home gardeners may start seedlings in peat, paper, or plastic cups, homemade newspaper cups, or other makeshift containers. In this project, we compared the growth of cabbage seedlings in plastic, peat, paper, or newspaper containers to see if any of these container types have an effect on seedling vigour and growth. In our experiments, we found cabbage seedling growth to be superior in plastic containers. We found seedlings grown in newspaper containers extremely stunted, suggesting that newspaper may contain substances harmful to cabbage seedling growth.

recycled or discarded, which may entail added disposal costs. Concern about disposal of plastic seedling containers, as well as recent research on the health effects of leaching of plasticizers toxic materials from plastic containers (Horn, Nalli, Cooper, & Nicell, 2004) has made some consumers generally wary of plastic products.

Peat containers can be planted directly in the ground, possibly reducing the severity of transplant shock. However, some consumers avoid the use of peat because the practice of peat harvesting may be unsustainable and possibly contribute to global climate change (Mitsch et al., 2012). An alternative material that may be planted directly into the ground is paper. Some commercial growers plant seedlings in commercially available paper containers, while some home gardeners make seedling containers out of newspaper. A variety of organic materials have been used to create biodegradable containers for experiments with seedling growth, including poultry feathers (Evans & Hensley, 2004) residual substrate from Ganoderma lucidum mushroom cultivation (Postemsky, Marinangeli, & Curvetto, 2016), straw (Jiang, Zhao, & Qu Ping, 2016), and tomato and hemp fibers (Schettini et al., 2013). While seedling growth in these containers has been shown to be comparable or even superior in some cases to seedling growth in plastic containers, the biodegradable containers tested in these studies are not yet widely available to commercial growers or consumers.

In this study, we compared cabbage seedlings grown in four types of containers currently used by commercial and home growers, plastic, peat, paper, and homemade containers made of newspaper, to determine whether the container material affects seedling growth. We examined physical and chemical aspects of the containers in connection to seedling growth under ordinary environmental conditions.

2. Materials and methods

2.1. Containers

Three types of commercially available containers were purchased: plastic [3 Oz White Containers (Wal-Mart, Bentonville, AR, USA)], peat [Jiffy Pots (Jiffy Products NB Ltd, Shippegan, NB, Canada)], and paper [unwaxed Dixie 3 Oz Bath Containers (Dixie, Atlanta, GA, USA)]. Following online instructions (Blackerby, 2011), newspaper containers were constructed by folding a 29 cm by 21 cm sheet of used newsprint (*Washington World*, East Montpelier, VT, USA) with black printing on both sides; sheets with coloured inks were not used (Figure 1). Peat containers had a pre-formed 1.2 cm drainage hole; a 1-cm-diameter drainage hole was drilled into the plastic and paper containers. Containers were approximately the same size; characteristics of the containers are presented in Table 1.

Figure 1. Construction of newspaper containers for growing cabbage seedlings.

Table 1. Dimensions of plastic, peat, paper and newspaper containers used to grow cabbage seedlings

Type	Top diameter (cm)	Bottom diameter (cm)	Height (cm)	Volume (cm^3)	Surface area (cm^2)
Peat	6.3	4.3	5.9	132	266
Plastic	5.6	3.9	6.0	107	234
Paper	5.8	4.1	5.8	113	241
Newspaper	5.5	5.5	5.0	119	268

2.2. Experiment 1: pH analyses of water exposed to container materials

For each material type (plastic, peat, paper, and newspaper), each of 3 plastic disposable 50 mL centrifuge tubes received 12 square centimeters of the material, cut into 1 cm^2 pieces, and 20 mL of de-ionized water. In addition, 3 controls were prepared by putting 20 mL of de-ionized water and no container materials into 3 separate centrifuge tubes; therefore, a total of 15 tubes were prepared for this study. The pH of the water in these tubes was measured immediately after adding the de-ionized water on day 1 and then once per day for a total of 14 days with a pH meter (HQ411d pH/mV; Hach Company, Loveland, CO). In between measurements, the test tubes were sealed with plastic lids to prevent evaporation. The pH meter was calibrated each day immediately before the measurements were taken.

2.3. Experiment 2: Evaporative loss of water over 35 days

Nine containers of each type (plastic, peat, paper, newspaper) were individually weighed, then filled with 30 g of uniformly moist soilless potting mix containing sphagnum peat, perlite, vermiculite, a wetting agent, and a starter charge [Lambert LM-3 (Lambert, Riviere-Ouelle, QC, Canada)]. The containers were placed in random order in one plastic tray. The tray was placed in the centre of the row of growth experiment trays and received full sun for approximately 11 h each day; ambient temperatures were 20–27°C. Every 1–3 days each container was weighed and the exact mass of tap water needed to return the container to the initial weight was added. Total water loss for each container was calculated by comparing the initial weight, the total volume of water added, and the final weight after 35 days (Table 2). We assumed that 1 mL of water weighed 1 g; thus, a decrease of 1 g in mass indicated a loss of 1 mL of water.

2.4. Experiment 3: Growth of seedlings

Fifty-four of each type of container (plastic, peat, paper, newspaper), 216 in total, were filled with 30 g of uniformly moist soilless potting mix [Lambert LM-3 (Lambert, Riviere-Ouelle, QC, Canada)], and a single cabbage seed [*B. oleracea* “Early Thunder” (Seedway, Hall, NY, USA)] was placed under the surface of the potting mix. Containers were randomly arranged in 6 plastic greenhouse trays which received full sun for approximately 11 h each day at ambient temperatures of 20–27°C. Moisture content of the potting mix was checked daily and tap water was delivered via squeeze bottle until the growth substrate appeared uniformly moist. Potting mix was never allowed to dry enough to cause observable wilting.

Seedlings were examined daily and growth stages recorded (emergence, first true leaf) as well as any developmental anomalies (e.g. malformed cotyledons or stems). After 35 days, stem height, stem width, number of leaves, and leaf diameter were measured for all seedlings. Sixteen seedlings of each type were randomly selected and removed from the containers. The roots of these seedlings were carefully washed in running water, and the length of the longest root was measured. Seedlings were cut at soil level into root and shoot portions and dried at 70°C for 63 h; dried roots and shoots were then weighed separately.

Table 2. Summary of experimental results for cabbage seedlings grown in plastic, peat, paper, and newspaper containers for 35 days

Container type	Average total evaporation at 35 days (mL)*	Average days to emergence*	Average days to 1st leaf*	Average stem diameter (mm)*	Average stem height (cm)*	Average shoot dry weight (gm)*	Average 1st leaf diameter (cm)*	Average root length (cm)*	Average root dry weight (gm)*	% Emergence	Average # of cotyledon deformities†	% With purple veins†	% With 2 leaves at 35 days†
Plastic	91.85^{a}	5.02^{a}	13.62^{a}	1.29^{a}	10.66^{a}	0.0258^{a}	1.84^{a}	16.71^{a}	0.0100^{a}	98.15%	1.44^{a}	0.00%^{a}	90.57%^{a}
Peat	163.67^{b}	5.65^{b}	14.86^{b}	1.10^{b}	9.05^{b}	0.0172^{b}	1.41^{b}	17.11^{a}	0.0056^{b}	98.15%	2.13^{b}	0.00%^{a}	26.42%^{b}
Paper	150.16^{b}	5.38^{b}	16.29^{c}	1.12^{b}	8.08^{c}	0.0162^{b}	0.96^{c}	17.45^{a}	0.0063^{b}	96.30%	1.24^{a}	15.38%^{b}	7.69%^{c}
News-paper	146.21^{b}	5.41^{b}	22.50^{d}	0.94^{c}	6.43^{c}	0.0116^{c}	0.47^{d}	22.58^{b}	0.0057^{b}	100.00%	1.24^{a}	57.41%^{c}	1.85%^{c}

*Within column means followed by different lowercase letters are significantly different $p < 0.05$ by 2-sample t-tests assuming unequal variances.

†Within column means followed by different lowercase letters are significantly different $p < 0.05$ by χ^2.

2.5. Statistical analyses
Differences between means for quantitative data were determined by 2-sample *t*-tests assuming unequal variances with significance at $p < 0.05$. Frequencies of qualitative characteristics were compared using X^2 tests with significance at $p < 0.05$.

3. Results

3.1. pH of water exposed to container materials
At the start of the experiment, immediately after adding water to the containers, on day 1 the average pH of the samples was between 6.92 ± 0.17 (95% confidence interval; newspaper) and 7.67 ± 0.10 (plastic; Figure 2). At day 4, the average pH in the samples with peat was 5.72 ± 0.32, newspaper 7.20 ± 0.23, controls 7.23 ± 0.11, paper 7.45 ± 0.17, and plastic 7.64 ± 0.17 (Figure 2). After day 1, the average pH of water in contact with peat decreased to a low of 5.72 ± 0.32 on day 4, then increased, but remained consistently significantly lower than the pH of the other samples throughout the rest of the 14 day experiment ($p < 0.05$; Figure 2). From days 4 to 14, the average pH of water in contact with newspaper was greater than the samples with peat each day, but significantly less than the samples with plastic, paper, or the controls ($p < 0.05$ for each day; Figure 2).

3.2. Evaporative loss of water over 35 days
Less water evaporated from plastic containers than from other container types (plastic compared to newspaper: $p = 0.000000162$; Figure 3), while differences between evaporation in the other container types did not differ.

3.3. Emergence and growth of seedlings in plastic, peat, paper, and newspaper containers
Days to emergence was shorter in the plastic containers than in the other types of containers (plastic compared to paper: $p = 0.035033$) while differences in days to emergence among the other types of containers were not significant (Table 2). Time from planting until the first leaf appeared was faster in plastic than peat ($p = 0.000256$), in peat than paper ($p = 0.013252$), and in paper than newspaper ($p = 0.00000000381$; Figure 4).

At 35 days, seedlings grown in plastic containers appeared to be larger and more robust (Figure 5). Seedlings grown in plastic containers had larger stems than seedlings grown in the other containers (plastic compared to paper: $p = 0.00000114$) while seedlings grown in newspaper had smaller stems

Figure 2. Change in average pH of water in contact with container materials for 14 days.

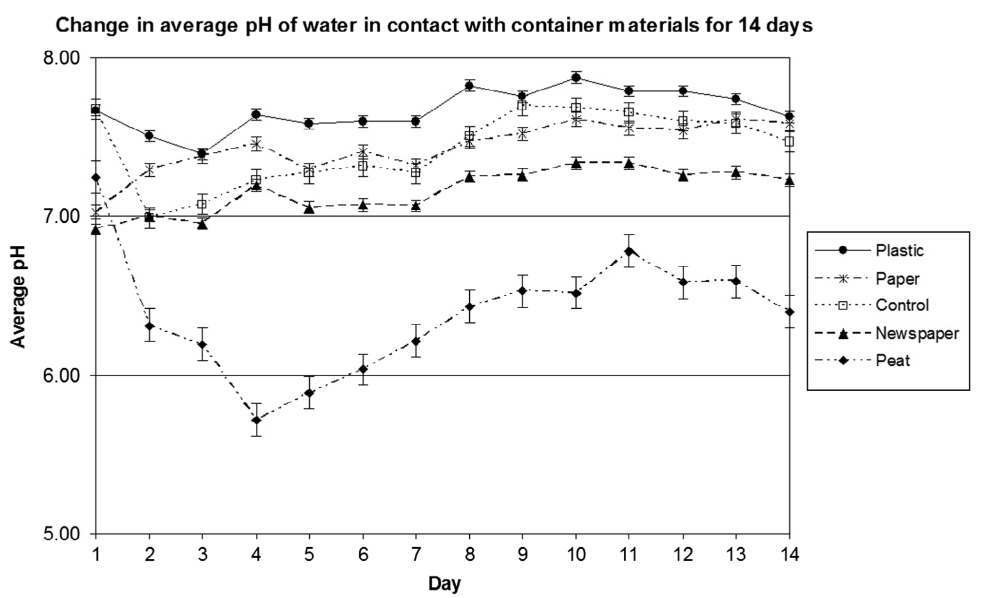


Figure 3. Average total water loss (by weight) over 35 days in plastic, peat, paper, and newspaper containers.

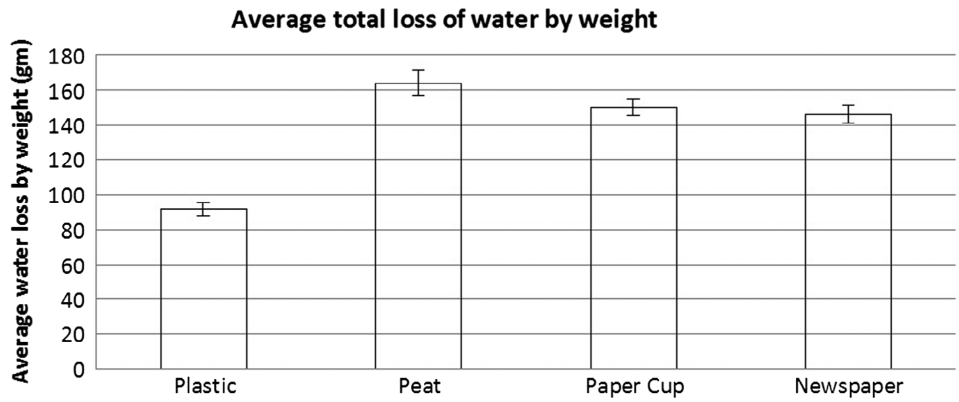


Figure 4. Average days to emergence and first true leaf of cabbage seedlings grown in plastic, peat, paper and newspaper containers.

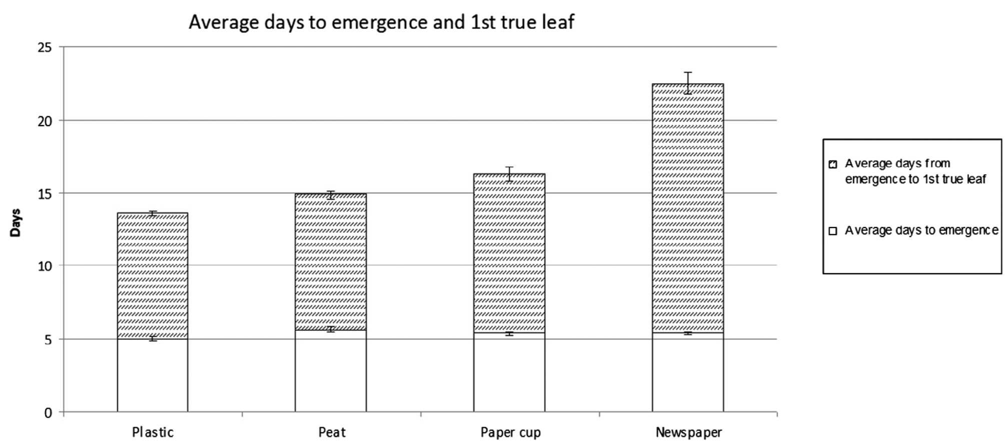
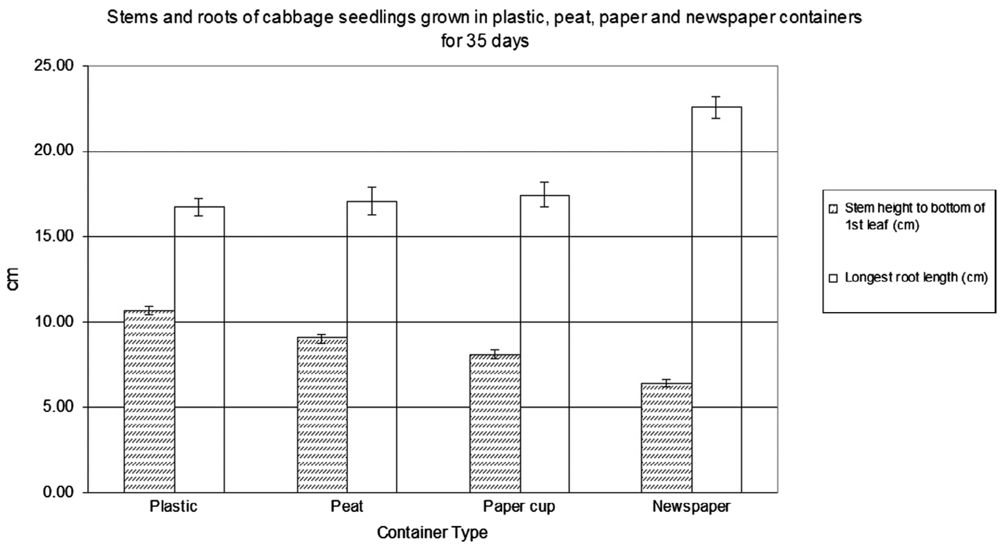


Figure 5. Typical cabbage seedling growth patterns in newspaper, paper, peat, and plastic containers.

Figure 6. Length of stems and roots of cabbage seedlings grown in plastic, peat, paper and newspaper containers for 35 days.



(newspaper compared to peat: $p = 0.000000296$; Table 2). Seedlings grown in plastic containers were taller than peat grown seedlings ($p < 0.00000498$), which were taller than paper or newspaper grown seedlings, (peat compared to paper: $p = 0.005567$; Figure 6). Newspaper grown seedlings had longer roots than seedlings grown in other containers (newspaper compared to paper: $p = 0.00000221$).

Average diameter of the first leaf at 35 days was wider in plastic-container grown seedlings than in peat-container grown seedlings ($p = 0.00000000101$), which was wider than paper-container grown seedlings ($p = 0.0000000189$), which was wider than in newspaper-container grown seedlings ($p = 0.000000000771$). At 35 days, more plastic-container grown seedlings had developed a second leaf compared to peat-container grown seedlings ($p = 0.0000157446$), while more peat-container grown seedlings had a second leaf than paper-container grown seedlings ($p < 0.018422$). Only 1.85% of the newspaper-container grown seedlings showed signs of a second leaf at 35 days. Dried shoot mass was greatest for the plastic-container grown seedlings and smallest for newspaper-container grown seedlings. Plastic-container grown seedlings also had the greatest dried root mass (plastic compared to paper: $p < 0.000149$).

No differences in germination rates occurred among the different container types. However, cotyledons showed a greater incidence of deformities, such as asymmetries, discolorations, or tears, in peat containers than in the other containers (peat compared to plastic: $p = 0.007737$). In addition, 2 of the seedlings grown in peat containers never developed stems, while this deformity did not occur with seedlings grown in the other container types. At 35 days, 57% of the newspaper-container grown seedlings had purple coloring in the leaves, compared to 15% of the paper-container grown seedlings, and 0% of the plastic- and peat-container grown seedlings (newspaper compared to paper: $p = 0.000230553$, paper compared to plastic: $p = 0.004678$).

4. Discussion

4.1. Growth in plastic containers

Seedlings grown in plastic containers developed faster and were more robust. They emerged fastest, had the greatest stem width and height, had more and larger leaves, and had the highest root and shoot dry weights at 35 days. The low rate of water loss from plastic containers compared to other containers may have promoted growth by ensuring a constant moisture level. Similar results showing superior growth in plastic containers were reported for cabbage (White, 1980), marigold, vinca and geranium (Evans & Hensley, 2004), geranium and vinca (Kuehny, Taylor, & Evans, 2011), and tomato (Sakurai, Ogawa, Kawashima, & Chino, 2005). Results of our evaporation study suggest that the superior growth found with plastic containers as compared with peat or other fibre containers may result from more uniform moisture in plastic containers.

4.2. Growth in peat containers

Seedlings grown in peat containers were slower to emerge and had the most deformed cotyledons. These effects may have been caused by leaching of organic acids or acidic metal ions, as suggested by the pH experiment (Figure 2). Acidic conditions have been shown to be deleterious to germination and growth in cabbages and other types of plants (Caporn & Hutchinson, 1986; Turner, Lau, & Young, 1988). Alternatively, slow emergence and deformed cotyledons in peat-grown seedlings could also be due to drying, since evaporative losses were highest in the peat containers in the evaporation experiment. Nevertheless, at 35 days, the growth characteristics of peat-grown seedlings surpassed those of the paper-grown seedlings, although they were still inferior to those of the plastic-container grown seedlings (Table 2).

4.3. Growth in paper and newspaper containers

Growth of seedlings in paper containers and newspaper containers was slow and stunted compared to seedlings in other container types (Table 2 and Figure 5). Minor evaporative drying may have contributed to slow growth. However, seedlings did better in peat than in paper, even though peat containers displayed greater evaporative drying.

After germination and emergence, growth of seedlings in newspaper containers was exceedingly slow. Newspaper-grown seedlings were short, spindly, and had few, extremely small leaves that were frequently highlighted with purple (Table 2 and Figure 5). Purple leaves suggest the presence of anthocyanins, a sign of stress. The newspaper-grown seedlings also had disproportionately long and un-branched roots. Their root dry weight was less than those grown in paper or plastic containers (Table 2), suggesting that long taproots may be another sign of stress. It is not likely that seedlings in the newspaper containers were subject to more drying than those grown in paper or peat, since water losses in newspaper containers were second lowest (Table 2). It is also not likely that the newspaper had an effect on the pH of the potting mix that was detrimental to growth since the pH of water in contact with newspaper was higher than the pH of water in contact with peat and lower than the pH of water in contact with plastic, and seedling growth was superior in containers of both those materials (Figure 2).

Microbial growth on the newspaper containers may have resulted in competition for nutrients between microbes and seedlings in the newspaper containers (Sipiläinen-Malm, Latva-Kala, Tikkanen, Suihko, & Skyttä, 1997). Although the paper containers were also made with wood fibres, the bleaching agents added to them may have discouraged microbial growth. Increased recycled paper in the growth medium has been found to stunt plant growth and cause chlorosis, and has been attributed to relatively high C:N ratio (Craig & Cole, 2000). Lack of available nitrogen has been found to affect growth in plants exposed to recycled paper fibres (Bellamy, Chong, & Cline, 1995).

An additional difference between the paper used in the paper containers and newsprint is that the paper containers were made with virgin wood fibres (Dixie 2012, personal communication), while newsprint is usually made with recycled wood fibres from the bottom of the recycling chain. When paper is recycled, the heavy metal content of the paper tends to increase, with various studies reporting high levels of cadmium, cobalt, mercury, lead, and chromium in recycled paper (Beauchamp, Charest, & Gosselin, 2002; Bellamy et al., 1995; Conti & Botrè, 1997; Storr-Hansen & Rastogi, 1988), as well as polychlorinated biphenyls (PCBs: Storr-Hansen & Rastogi, 1988) and bisphenol A (BPA: Gehring, Tennhardt, Vogel, Weltin, & Bilitewski, 2004). Other research has shown variable or negative results for using recycled paper as mulch for lettuce (Runham, Town, & Fitzpatrick, 2000), strawberries (Boyce & Heleba, 1991), and forsythia (Cole & Newell, 1996).

Of the four types of container materials tested, plastic containers were superior for promoting rapid growth and robust seedlings through the first 35 days following planting of cabbage seeds. Peat containers were second best, paper containers third, and newspaper containers the worst of the container types tested. Growth was exceedingly slow and seedlings were markedly stunted in newspaper containers, suggesting that exposure of cabbage seedlings to newspaper should be avoided. The degree of stunting of the newspaper container-grown seedlings was so severe that recommendations for incorporating newspaper into garden soil, even when printed only with soy-based inks, should be re-examined.

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Competing Interests
The authors declare no competing interest.

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